Def Sci J, Vol 38, No. 2, April 1988, pp 131-140

Criteria for Selection of Site for Construction of Structures on a Floating Ice Shelf in Antarctica—A Case Study

Satya S. Sharma

Research & Development Establishment (Engineers, Pune–411 015

ABSTRACT

The coastal regions of Antarctica, where substantial deposits of oil and other minerals are reported, consist of a number of ice shelves. Such areas encounter severe weather conditions and flow of the ice shelf which severely affect the life of the structure/installations. The Indian Antarctic station Dakshin Gangotri located in east Antarctica at 70 degrees S 12 degrees 05′ E lies on one of such ice shelves. The paper brings out the criteria which should be kept in mind while selecting the site of a structure on an ice shelf, and a case study for selection of site of Indian research station Dakshin Gangotri in December 1983 of which the author was the leader of the first wintering party.

INTRODUCTION

The third Indian Antarctic Expedition constructed the first Indian Antarctic research station, Dakshin Gangotri during December 83–February 84 on an ice shelf in east Antarctica. The complete construction, including selection of site, digging of foundation, construction of superstructure and setting up of laboratories was completed in nearly forty five days. The site of the station was tentatively finalised in the ship while on way to Antarctica and was finally approved on reaching the shelf. The factors considered during the technical appreciation and analysis, and deductions made reveal that the correct selection of site requires a careful scientific analysis of the ice shelf and its surrounding areas, the snow accumulation pattern, and the general topography of the area.

Received 25 March 1987

Reproduced, with permission, from Symposium series of the Technical Research Centre of Finland, No 73, Vol. 3, POLARTECH'86 Conference

2. ANTARCTIC ICE SHEET/GLACIER

Of the total area of 14.5 million square km of Antarctic continent, glaciers cover over 98 per cent of the area, and this represents by far the greatest amount of glacier covered area in the world. The area free of ice consists of high mountain peaks which project as nunataks above the ice surface, and isolated 'oases' of ice free ground. As per Sugden[1], the entire ice covered area can be sub-divided into three categories, viz, (i) Ice sheet and ice cap, (ii) Ice shelf, and (iii) Glaciers constrained by topography.

2.1 Ice Sheet and Ice Cap

The ice sheets and ice caps build up on flattish land area and superimpose a roughly radial outflow of ice over the area. This is further sub-divided into ice dome and outlet glacier. The domes build up over the underlying relief and may completely submerge mountain ranges and basins with little sign of the achievement on the ice surface. Parts of the Antarctic ice domes are as much as 4300 m thick. The domes have a convex-upward profile as shown in Fig. 1. Each ice particle in a dome, due to its viscous nature of flow, remains in constant motion which is known as ice creep. The motion is retarded or accelerated depending on the slope configuration, presence of any surface protrusion, and other boundary constraints. The surface of the dome is the accumulation zone where accumulation of snow/ice takes place due to precipitation, absorption of moisture from air, and drift snow accumulation. The ablation takes place primarily by calving of icebergs into sea. Based on the measurements of the movements of this ice sheet carried out in past in various parts of Antarctica, Loewe[2] takes the average value as 15 to 30 m per year for a realistic estimate of mass balance. Outlet glaciers are a component of the peripheral parts of ice domes which may drain the bulk of ice from the dome. They consist of glaciers constrained by rock walls which may push many kilometres beyond the ice dome margin. There are a number of outlet glaciers cutting through the Transantarctic mountains. One of these glaciers is Beardmore glacier which is some 200 km long and 23 km wide and flows at a velocity[1] of around 1 m/day.

2.2 Ice Shelves

An ice shelf, which can be called as a floating sheet of ice, is primarily an extension of the continental ice sheet or glacier into sea. It is an overhanging mass of ice into the sea which is floating over the sea water, and is continuously in motion. It gets its accumulation by the falling snow, wind transportation and from creep motion of ice dome or land based glacier. The ice shelves occupy as much as 30 per cent of the length of the coastline in Antarctica. The two largest of these are Ross ice shelf in Ross sea in the lower part of Antarctica extending from 160 degrees E to 140 degrees W, and Ronne/Filchner ice shelf in the Weddel sea in West Antarctica extending from 30 degrees W to 80 degrees W. The Ross ice shelf is about 30 m above sea level and it extends some 900 km inland and 800 km across. The ice thickness of an ice shelf is commonly 200 m but may go upto as much as 1000 m. The top surface of an ice shelf is virtually flat and gives a look of an ice sheet. A sketch of the ice shelf is shown in Fig. 1(b). The primary source of accumulation on an ice shelf is by fresh snow

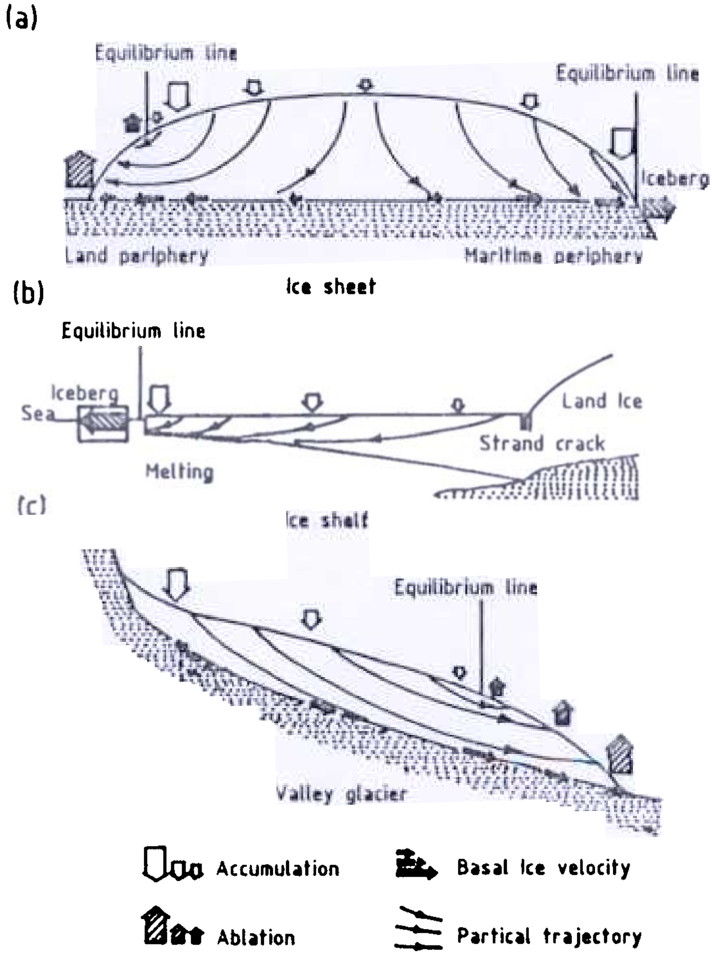

Figure 1 Models of (a) Ice Sheet, (b) Ice Shelf, and (c) Valley glaciers showing the distribution of accumulation and ablation and related flow characteristics.

precipitation, drift accumulation and supply of ice from land ice. As in the case of ice cap, the primary source of ablation in case of ice shelves is also by calving of icebergs into sea of thickness of 200 to 300 m and of varying dimensions. In Antarctica, icebergs up to 144 km long have been observed to break away from ice shelves. The junction of overhang portion and land ice is known as strand-crack which is prominent by the presence of a number of crevasses in the general area. The entire shelf floats over the sea water and moves up and down with waves and tides. Like in ice cap, each particle of ice in an ice shelf is in constant motion towards the sea due to ice creep. An ice shelf moves seaward with a velocity of .8 to 2.8 km per year[1]. Mellor[3] as quoted by Loewe[2] has carried out measurements of velocity on some of the ice shelves in Antarctica, and obtained an average velocity of 400 m/year. However, for individual cases for the purpose of planning a station, exact value should be ascertained by physical measurements over a period of two to three years. Climatically, ice shelves.

being nearer to coast, experience severe blizzards and precipitation. Wind speed of the order of 200 km/hr and annual snow precipitation of the order of 20 to 40 cm of equivalent water are a common feature.

2.3 Glaciers Constrained by Topography

These are small in comparison to the previous categories and are closely influenced in their shape and direction of flow by the form of the underlying ground. They are located on the raised features above the normal lay of ground. In Antarctica, their number is not very significant.

3. IDEAL SITE OF A STRUCTURE/INSTALLATION ON AN ICE SHELF

Any structure built on a floating ice shelf is a temporary structure in view of horizontal and vertical creep of snow and snow accumulation due to precipitation and blizzards. The horizontal and vertical creeps are due to viscous nature of deformation of snow. Because of continuous creep motion of the shelf, any structure built on an ice self is continuously in motion; the velocity, however, varies from shelf to shelf. With the horizontal creep, the structure continues to move forward and may find itself on an iceberg with the passage of time, and with the vertical creep and snow accumulation on shelf, the structure, in due course of time, may be deeply buried that it is inaccessible.

To quote a few examples, the present South African station Sanae at 70 degrees 19′ S 2 degrees 22′ W built in 1979, has moved by 3.5 kms towards north and is buried under 10 m of snow in the last five years. The horizontal creep in this region is approximately 700 m/year and snow accumulation is of the order of 1 m/year (personal communication with Dr Malcolm Heim on radio on 2 October 1984). Another example is Camp Michigan (USA), on Ross ice shelf which was built in late fifties and was found on the side of an iceberg[1] in 1972. In view of the above, the ideal site for a structure on an ice shelf should meet the following requirements, as far as possible :

(i) The site should be farthest from the shore in order to have a longer life span of the structure.

(ii) It should be away from the strand-crack region in order to avoid open water channels, crevasses, and possible areas prone to cracks.

(iii) The structure should be on an open area free of crevasses to facilitate installation of various scientific instruments, free movements of human beings and vehicles around, and wide dispersal of various objects and installations.

(iv) The site should, as far as possible, be on a flat topped area having a uniform uniaxial gradient of the shelf from strand-crack region to the sea edge. Such a site minimises the chances of deep crevasses and surface cracks in the area around. The areas having too many undulations are the potential tension and compression zones which cause fractures in the snow cover resulting in crevasses of varying dimensions. The uniaxial flow of the shelf also minimises differential movements within the tructure, thereby increasing the effective life of the same from structural stability point of view

(v) The location should not be in the close vicinity of a hillock or a raised snow hill in order to prevent snow accumulation due to blizzards.

(vi) The snow cover at the site should be medium hard of density .4 to .5 gm/cc in order to prevent unequal settlement of the structure. A very hard snow cover of higher density, close to that of ice, is more prone to cracks due to its low lexibility.

(vii) The site should not be too far from the ship-offloading point from the point of view of the logistics involved in stocking and maintaining the installation in summer, on arrival of ship.

4. CASE STUDY

The above norms which are primarily based on structural behaviour of snow and ice related to glaciers were applied while selecting an ideal site for Dakshin Gangotri (DG) station in the coastal region of east Antarctica on an ice shelf, in December 1983. The various sites considered together with their merits and demerits are discussed in succeeding paragraphs in brief.

4.1 Dakshin Gangotri Ice Shelf

4.1.1 Geographical Layout

The Dakshin Gangotri ice shelf is part of the unnamed ice shelf extending from 69 degrees 50′ S to 70 degrees 45′ S widthwise, and 08 degrees 30′ E to 13 degrees E lengthwise, along the periphery. It has Fiambul Ice Shelf on its west which extends from 10 degrees W to 7 degrees 30′ E and an unnamed ice shelf on its east which extends from 13 degrees E to 33 degrees E. The complete ice shelf runs along the Princess Astrid Coast in a zig-zag manner. Extentwise, its average width is 70 km and length along the coast is 150 km. It is a flat-topped ice shelf having a gradual southward ascent of approximately 80 m in 90 km from sea edge to its point of origin at the foot of the Schirmacher oasis. There is no station functioning at present on this shelf except the Indian station which has recently been established. The other station in the general area is Lazarev at 69 degrees 59′ S 12 degrees 55′ E belonging to Soviet Union, which was abandoned by them in early sixties and a part of which has already formed part of an iceberg in the last few years.

4.1.2 Topography

The shelf originates from Schirmacher oasis which is an open patch of ground on a hillock located at about 90 km from the northern edge of the DG ice shelf towards south. The oasis has an average altitude of 100 m extending from 11 degrees 49′ E to 11 degrees 26′ E and a total area of approximately 35 square km, of which 27 square km is bedrock, 3 square km lagoons, 3 square km firn/ice fields and 2 square km lakes. By virtue of the presence of so many fresh water lakes on and around the oasis, the area of Schirmacher oasis has been termed as Schirmacher lake district[4].

The depth of lakes in this region varies from 5 to 13 m and the water in these lakes is available practically throughout the year. The current Soviet Union station known as Novolazarevskaya is located in the oasis at an altitude of 105 m at the foot of a glacier. The DG ice shelf starts from the foot of the northwall of the Schirmacher oasis which can rightly be termed as the hinge point or the strand-crack area of the shelf. All along the southern edge of this shelf, there are large to very large lakes having depths as much as 100 m. Prominent of these lakes are Lake Ozhidaniya which has an area of 1.4 square km and maximum depth of 105 m, and Lake Zig-zag of depth 122 m. The lakes are permanently covered with ice[4]. In this region there are shallow seasonal streams of fresh water running from west to east making this area inaccessible for snow vehicles in summer months. In this area of origin, there are a number of crevasses which are deceptive in nature by virtue of their being covered by snow bridges during most of the time of the year. The crevasses are as a result of surface fracture caused by movements of the shelf due to tidal waves about the hinge points of the strand-crack region.

4.1.3 Lay of the Shelf

From the lay of the general area, the shelf is uniformly sloping from the foot of the Schirmacher oasis in south to the shelf edge in north with the average gradient being 60 m in 100 kms. Along the edge of the shelf there are two high grounds of height 70 to 80 m which are permanently covered with ice.

4.1.4 Thickness of the Ice Sheet

Some measurements of thickness of the shelf were carried out in 1984–85 and accordingly the ice thickness on the seaward edge varies from 200 to 300 m, of which approximately 15 to 20 m is exposed above the sea level. Measurement of the ice sheet thickness in the interior of the shelf were carried out by Soviet Union scientists in 1975 and the thickness measured is tabulated below[5] :

Table 1. Thickness measurements of DG ice shelf ice sheet

Serial number of hole	Location	Date of drilling	Depth observed (m)
	70 degrees 22.8′ S 12 degrees 21.4′ E	Jan-Aug 1975	374
2	70 degrees 13.2′ S 11 degrees 53.3′ E	Oct 1975	357
	70 degrees 23.6′ S 11 degrees 39.6′ E	Aug 19	

4.1.5 Movement of the Shelf Ice

Data on shelf movements towards sea are not available. However, from the USSR shore station located at the shelf edge, it is seen that the shelf movement is not very significant, though a number of icebergs of small size are calved every year. The slow movement is obvious because of its origin from the foot of Schirmacher hill which is an ice free area, and gradual descent of the shelf from south to north. This could also be attributed to the presence of ice covered high grounds on the northern edge of the shelf. At the same time the shelf on the eastern side of DG ice shelf has a very high velocity of the order of 1 to 3 km/year which is due to its origin being from ice resting on a steep slope (discussions with Igor Simonov, leader Novolazarevskaya station, 1984).

4.1.6 Craters on the Shelf

The Norwegian scientists, who are reported to have carried out detailed study of this shelf have reported crater formation in the general area of this shelf. As per them, large areas of the shelf have been seen sinking into the sea in past and as such the shelf is not suitable for occupation. However, during reconnaissance, no evidence of such craters was noticed.

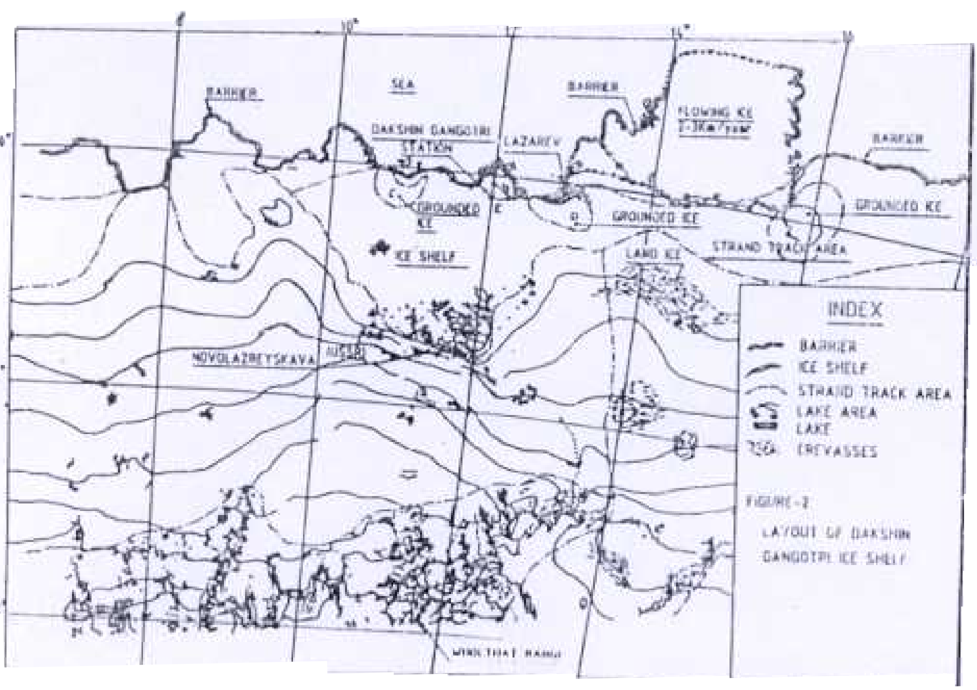

Figure 2. Layout of Dakshin Gangotri ice shelf

4.2 Sites Considered

Based on the information available from past expeditions, the following four sit were considered which are shown in Fig. 2:

(i) Area near the shelf edge – Site A.

(ii) Near the old skiway – Site B.

(iii) On top of the high features – Sites C and D.

(iv) Midway between shelf equilibrium point and strand-crack region–Site E.

4.2.1 Area Near the Shelf Edge Site A

The site A was indicated by the Second Indian Antarctic Expedition in view its being very close to the ship off-loading point, availability of hard ice cover ar close proximity to the USSR shore station. This site was, however, rejected in vie of its possibility of finding itself on an iceberg within a period of two years, takir into consideration the average velocity of shelf movement as 1 km/year. This veloci was assumed in the absence of any authentic data being available at the time planning. Further, due to the presence of hard ice and proximity to equilibrium poin distinct cracks in ice are apparent which are a clear indication of potential icebe formation zone. In the past, distinct noises indicating crack formulation/crack wideni have been recorded by the Second Indian Antarctic Expedition.

4. 2 Near the Old Skiway Site B

The site lies very close to the skiway prepared by the Second Indian Antarct Expedition, as well as lies very close to the ship off-loading area (7 km) which reduc the logistics for supply by air as well as by ship. However, this site was rejected view of the presence of a very high density snow at a depth of only 50 cm and possibility of its finding itself on an iceberg in about seven years taking the veloci of the shelf as 1 km/year. Further, there were many undulations in the general ar which gave an indication of high wind activity in this area.

4.2.3 On Top of the High Features Sites C and D

The sites C and D which lie on raised features on east and west of the coast we studied and it was found that the two raised features are as a result of grounded ic The seabed under these features is protruding up which has given hump shape these features. Thus, scientifically, these features are not part of floating ice shelf b part of grounded ice. The sites were recommended in order to avoid any possibili of the station finding itself on an iceberg and going down into the sea in a crater. Tl sites are also in close proximity to ship off-loading area. However, these sites we rejected in view of a high possibility of crevasse formation all around the high feature especially at the convex and concave faces of the features, as well as at the border grounded ice and shelf ice. This was later verified from the aerial and groun reconnaissance carried out after arrival in Antarctica.

4.2.4 Midway Between Shelf Equilibrium Point and Strand-Crack Region – Site E

The site E, where the present station is located, was finally selected in view of its meeting all the requirements enumerated earlier. The site is though 17 km from the shelf edge which involves a bit of logistic problems being far off from the ship off-loading area, however, it offers a good compromise in view of many other advantages. The site lies approximately 70 km from the strand-crack area and 40 km south of the lakes and streams, which provides good accessibility to the station from all sides, throughout the year. Though this shelf is fairly stable, however, even at 1 km/year of shelf flow, the station will remain functional for a period of at least 10 to 15 years. The snow cover in this area has an average density of .45 gm/cc in layers which gives it good flexibility to take stresses, without resulting into crevasse formation. The area is open and flat and there is enough room for wide dispersal of various installations as well as for further expansion of the base. Last but nôt the least, it provides a good aesthetic view as one can see the icebergs on the north, and Schirmacher hill rocks on the south, which break the monotony of the persons living there during winter.

The above study for selection of site was taken up and completed during the voyage to Antarctica based on the aerial photographs and data available from previous expeditions. These facts were later verified on arrival in Antarctica and the site so selected in the ship was finally approved within two days and the construction was commenced immediately. The construction of the station was completed in Feb 84 and the wintering party was left behind. The station has been functioning well for the last 3 years without any problem.

5. CONCLUSION

The time available for reconnaissance for selection of site and also for construction of a structure/installation in Antarctica on an ice shelf is limited. The maximum period available for the entire process is not more than 60 days which is a very small period. A correct scientific analysis of the ice shelf based on the past data, coupled with the guidelines given above, can greatly cutdown the time for selection of site.

REFERENCES

Sugden, D., Arctic and Antarctic : A Modern Geographical Synthesis, (Basil Blackwell Publishers Limited, Oxford), 1982, p.63, 69–71.

Loewe, F., Notes concerning the mass budget of Antarctic inland ice, *In* Antarctic Meteorology – Proceedings of the symposium held in Melbourne, February, 1959, (Pergaman Press, Oxford), 1960, p.364.

Mellor, M., *J. of Glaciology*, **3** (1959).

4. Richter, W. & Strauch, E., Deuterium and ^{18}O variations in lakes of the Schirmacher oasis (east Antarctica), *In* Isotopes in Antarctic Research – Contributions of the GDR, (Academy of Sciences of the GDR, Central Institute for Isotope and Radiation Research, Leipzig), May 1982, p.56–58.

5. Korotkevich, Y.S., Savatyugin, L.M. & Morev., Drilling through the ice shelf in the vicinity of Novolazarevskaya, *In* Bulletin of The Soviet Antarctik Expedition, Report No. 98, (Hydrometeo, Leningrad), 1978, p.50.